

**Clouds and the Earth's Radiant Energy System (CERES)**  
**Validation Plan**

***CERES Inversion to Instantaneous TOA Fluxes***  
***(Subsystem 4.5)***

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## CERES INVERSION TO INSTANTANEOUS TOA FLUXES

### 4.5.1 INTRODUCTION

There are several steps in converting measured radiances into flux at the TOA. The first step is to apply the Spectral Correction Algorithm (ATBD 2.2.1) to convert filtered radiances from each channel to unfiltered radiances of shortwave and longwave. The validity of both the algorithm and the radiance measurements are discussed in Section 2.0. Next, we must know the scene type of the area we are examining so that the proper Angular Distribution Model (ADM) can be used. The cloud parameters that define the scene type are validated in Subsections 4.1 - 4.3 and averaged over the CERES footprint in Subsection 4.4. And finally the unfiltered radiances are inverted to the top of the atmosphere (TOA) by

$$\hat{F}_j = \frac{\pi I_j}{\hat{R}_i(\Omega)} \quad (4.5-1)$$

where  $I_j$  ( $j$ =SW, LW, WN) are the CERES unfiltered radiances,  $\hat{F}_j$  are the corresponding flux estimates at the TOA, and  $\hat{R}_i(\Omega)$  are the angular distribution models (ADM) that relate radiance to flux for the  $i$ th scene type. This section will concentrate on the validation of the ADM and the bias and variance of an instantaneous flux estimate from errors in the measurements and ADMs.

The CERES radiances will be inverted with two different sets of ADMs and scene identifications. In Section 2.0 we validate the ERBE-like inversion to the TOA fluxes using the Maximum Likelihood Estimation (MLE) technique (Wielicki and Green 1989) and the ERBE ADMs with 12 scene types (Suttles et al. 1988, 1989). In this section we are concerned with the inversion to TOA fluxes using cloud parameters (Subsection 4.1-4.3) to define the scene type and a new set of CERES ADMs with 200 scene types. These new ADMs will be constructed from CERES radiance data.

#### 4.5.1.1 Measurement and science objectives

The CERES scanning radiometers measure the earth radiance in three spectral bands and are discussed in Section 1.1.1. We will refer to these measurements as the shortwave (SW), total (TOT), and window (WN) measurements.

The CERES ADMs will be constructed from valid CERES collocated radiance pairs with the Radiance Pairs Method (RPM) (see ATBD Subsection 4.5, Green and Hinton 1996).

### **4.5.1.2 Missions**

The CERES scanners will be launched aboard the TRMM spacecraft and the EOS AM and PM platforms (see Section 1.1.2)

### **4.5.1.3 Science data products**

The science data product for this section is the instantaneous TOA flux as recorded on the Single Satellite Footprint Product (SSF) (ATBD Section 4.0 App. B-3) which also contains measurement time, viewing geometry, CERES radiances, imager radiances, scene type, TOA fluxes, surface fluxes, and cloud statistics.

## **4.5.2 VALIDATION CRITERION**

### **4.5.2.1 Overall approach**

We will use several different tests to validate the ADMs. The SAB Method (Sorting by Angular Bins) determines the monthly regional flux without scene identification or ADMs. It is compared to the normal ADM inversion and differences are considered ADM errors. The Along-Track Test collects radiance data that views areas along the ground track from multiple angles. From this data we can validate the shape of the ADM and test for erroneous flux growth with viewing zenith angle. The MISR Comparison Test will require MISR and MODIS data and test the ADMs against independent data. We will also examine several desirable ADM characteristics.

#### ***4.5.2.1.1 The SAB Method***

The SAB Method is taken from the work of Suttles et al. 1992 where they validated the ERBE12 ADMs against the Nimbus-7 ERB data from which the ADMs were constructed. This is a consistency check between the ADM models and the underlying data. The same method will be used to validate the CERES200 ADMs against CERES data. The monthly regional fluxes are determined by the SAB Method and compared to the regional fluxes from the normal ADM inversion (4.5-1). The differences are attributed to ADM bias errors.

The SAB method does not use ADMs. It sorts all radiances for a month into angular bins for a given region, averages the radiance in each bin, and integrates over the angular bins to determine a monthly regional flux. This method relies on long term averages and uniform angular sampling. The Nimbus-7 ERB with its two-axis scanner provided good angular sampling and was well suited to the SAB method. The CERES scanner in the Rotating Azimuth Plane mode (RAP) will give similar data with a higher data rate. Thus, a month of data should be sufficient to average out scene changes and give good averages. The SAB results are compared with the average of all instantaneous flux estimates of the same region using the ADM inversion. Both methods use the same data, but one uses ADMs and the other does not. Under ideal conditions, both methods should give the same results. The SAB results are taken as truth since they are independent of ADMs. Any differences are considered ADM errors.

It should be pointed out that the SAB results are not true monthly average fluxes because no diurnal effects have been considered. These results are instead the average of all monthly sampling. CERES incorporates diurnal effects in its time averaging and needs instantaneous fluxes so

that SAB results are of no help. The SAB results, however, are most useful for ADM validation.

Suttles et al. 1992 have shown that the ERBE12 ADMs can reproduce the monthly average 4.5 deg regional fluxes with a 3% global bias in shortwave and a -1% bias in longwave. These results used all of the viewing zenith angle data in the ADM method. Since the accuracy of the scene identification and the ADMs is poor at shallow viewing zenith angles, these comparisons were also computed for a 70° viewing zenith cutoff. The bias differences for this case were reduced from 3% to 1% for shortwave and from -1% to +0.5% for longwave. These results showed a viewing zenith dependence in the ADM method. It was determined that the problem was not with the scene identification algorithm, but with the ADMs. The viewing zenith dependence was made clear by determining the global mean separately for each viewing zenith angular bin. These results showed a 6% drop in longwave flux from the nadir data to the near limb data and about a 10% rise in albedo. Thus, the SAB Method can be used to detect ADM biases and erroneous angular dependences

It should be noted that the CERES200 ADMs cannot be validated against the Nimbus-7 data as were the ERBE12 ADMs. The identification of data into the 200 CERES scene types requires imager data and the extensive set of cloud algorithms in Section 4.1-4.3. Since we do not have detail cloud data for Nimbus-7, we cannot determine the scene types needed to validate the CERES200 ADMs. Thus, we validate the CERES200 ADMs against CERES data.

#### ***4.5.2.1.2 Along-track Test***

The purpose of the ADMs are to remove the angular dependence from the radiance to flux conversion. A test of the ADM to accomplish this is to determine the TOA flux as a function of the viewing zenith. A valid set of ADMs should produce near constant flux independent to the viewing angles. The ERBE mission has produced several special along-track data sets for this purpose (Smith et al. 1989a, 1989b, 1990). From August 3 to 9, 1985 the ERBS scanning radiometer was rotated in azimuth to scan along track in the plane of the orbit. In this mode the scanner views a site along the ground track from a full range of viewing zenith angles and we can determine the flux for different angles. Green et al. 1990 has shown that this data and the ERBE12 ADMs resulted in a 10-15% albedo rise from nadir to the limb which agrees with the Suttles SAB results using Nimbus-7 data. The great advantage of the along-track data is that we are assured that each viewing zenith data set views the same along-track area so that it should get the same flux without having to rely on long-term data averaging. Any drop in the longwave flux from nadir to limb can be associated with an ADM limb-darkening error. For shortwave we only sample a slice through the viewing zenith - azimuth hemisphere. However, knowing the variance of the ADMs, we can test that this realization falls within the expected range.

#### ***4.5.2.1.3 MISR Comparison Test***

One of the purposes of the MISR mission is to estimate narrow band bidirectional reflectance functions. MISR has the capability of multi-angle sampling along the groundtrack. Since we have CERES, MODIS, and MISR on the same spacecraft, we can scenetype the MISR radiances the same way we scenetype the CERES radiances and compare the resulting MISR ADMs to the CERES200 ADMs.

#### **4.5.2.2 Sampling requirements and trade-offs**

The CERES200 ADMs must be constructed before they can be validated. A minimum of 18 months of CERES TRMM data is required to construct the new ADMs.

#### **4.5.2.3 Measures of success**

The purpose of increasing the number of ADMs from 12 to 200 is to reduce the variance within a scene type class and thus reduce the variance of the instantaneous flux at the TOA. Our current estimate of the variance for 12 scene types is given by Table 4.5-1 as 12% standard deviation for SW. We are successful when we have defined 200 scene types so that the variance is reduced from 12% to 4% standard deviation. Likewise, our LW goal is reduction from 6% to 2%. These reductions in variance are from increased scene types. The reduction in maximum bias is from the new RPM Method (Green and Hinton 1996) of constructing ADMs.

### **4.5.3 PRE-LAUNCH ALGORITHM TEST/DEVELOPMENT ACTIVITIES**

Pre-launch to TRMM there will be a validated set of ERBE12 ADMs. This set may be the ERBE production models (Suttles, et al., 1988, 1989) or it may be a new updated ERBE12 set with the biases removed. In either case these ERBE12 ADMs will be used initially for both CERES and ERBE-like inversion. When the validated CERES200 ADMs become available, all the CERES data will be reprocessed with these new ADMs.

#### **4.5.3.1 Field experiments and studies**

#### **4.5.3.2 Operational surface networks**

#### **4.5.3.3 Existing satellite data**

### **4.5.4 POST-LAUNCH ACTIVITIES**

After 18 months of data collection, a new set of CERES200 ADMs will be built with CERES RAP data. These models will be validated with the SAB Method with a month of CERES data. We will also apply the Along-track Test to all these new ADMs and the MISR Test to the short-wave ADMs.

Although validated with the SAB Method and the Along-track Test, the initial ERBE12 ADMs will be validated against the first TRMM RAP data. By selecting the appropriate RAP data, we can acquire along-track data for TRMM. An along-track test for flux growth with viewing zenith angle will reconfirm the initial ERBE12 models. If flux is not constant with this test, then there exists biases with the ADMs or a viewing angle dependent error is present in the data.

**4.5.4.1 Planned field activities and studies****4.5.4.2 New EOS-targeted coordinated field campaigns****4.5.4.3 Needs for other satellite data****4.5.4.4 Measurement needs at calibration/validation sites****4.5.4.5 Needs for instrument development****4.5.4.6 Geometric registration site****4.5.4.7 Intercomparisons**

The ERBE-like inversion (Section 2.0) and the CERES inversion (Section 4.5) both produce TOA flux estimates from the same radiance data. Initially, both will use the same ADMs and only the scene identification will be different. For this case we would expect little difference in the mean TOA flux. Pre-launch studies with ERBE NOAA-9 data inverted with ERBE-like and CERES scenes will set the expected differences.

When the validated CERES200 ADMs become available, we will still intercompare the ERBE-like and CERES TOA fluxes. Although the variance between the two fluxes will increase, the mean difference should be small and give an indication of the flux bias due to scene identification and ADMs biases.

**4.5.5 IMPLEMENTATION OF VALIDATION RESULTS IN DATA PRODUCTION****4.5.5.1 Approach**

The actual ADM or anisotropy associated with a single measurement varies from scene to scene. To reduce this variance, we have divided all scenes into a finite number of scene classes and estimated the mean ADM for each scene class. There is still, however, variance within a scene class due to unmodelled anisotropic effects. Thus, we consider the ADMs as random variables and define the TOA flux bias and variance due to inverting a measured radiance to flux with a constant mean model instead of the actual realization.

The current accuracies and goals for CERES are given in the Table 4.5-1. The following definitions are used in the discussions of accuracy where  $E[x]$  is the expected value of  $x$  and  $\text{Var}[x]$  is

the variance of  $x$ . The true flux at TOA is  $F = \frac{\pi I}{R_i(\Omega)}$ . The CERES radiance measurements are modelled as  $m = I + \varepsilon$  where  $\varepsilon$  is the instrument error and  $E[\varepsilon] = \varepsilon_{\text{bias}}$  and  $\text{Var}[\varepsilon] = \sigma_\varepsilon^2$ . The difference between the true anisotropy  $R_i(\Omega)$  and the estimate of the mean anisotropy  $\hat{R}_i(\Omega)$  is denoted by  $\delta R_i(\Omega) = R_i(\Omega) - \hat{R}_i(\Omega)$  so that

$E[\delta R_i(\Omega)] = R_{\text{bias}}(\Omega)$  and  $\text{Var}[\delta R_i(\Omega)] = \sigma_{R(\Omega)}^2$ . It follows that the estimate of flux at the TOA is

$$\hat{F} = \frac{\pi m}{\hat{R}_i(\Omega)} = \frac{\pi(I + \varepsilon)}{R_i(\Omega) - \delta R_i(\Omega)} \approx \frac{\pi(I + \varepsilon)}{R_i(\Omega)} \left[ 1 + \frac{\delta R_i(\Omega)}{R_i(\Omega)} \right]$$

or

$$\hat{F} = F \left[ 1 + \frac{\delta R_i(\Omega)}{R_i(\Omega)} + \frac{\varepsilon}{I} \right]$$

If we express the biases and variances in percent, then it follows that the instantaneous TOA flux bias is

$$E[\hat{F}] = F[1 + R_{\text{bias}}(\Omega) + \varepsilon_{\text{bias}}]$$

$$\hat{F}_{\text{bias}} = \frac{E[\hat{F}] - F}{F} = R_{\text{bias}}(\Omega) + \varepsilon_{\text{bias}}$$

$$\frac{\text{Var}[\hat{F}]}{F^2} = \sigma_{R(\Omega)}^2 + \sigma_{\varepsilon}^2$$

We see that the biases in the ADM and the measurements directly affect the bias in the flux estimate. Since the variance of the ADMs is generally larger than the variance in the measurements, the flux variance is approximately equal to the ADM variance and not a strong function of the measurement variance.

Suttles, et al. (1992) have shown that the ERBE production ADM models as a set and over all data and all angles have a bias of about 1% for shortwave and about 0.5% for longwave. They also showed that the bias was a function of the viewing geometry  $\Omega$ . The bias in shortwave flux grew by about 10% from nadir view data to near limb view data. The bias in longwave flux fell by about 6% over the same range. If we consider the midpoint to have no bias, then we can have biases at a given  $\Omega$  as high as 5% for shortwave and 3% for longwave. These biases come from models that do not match the mean or expected  $R$ . The variance of an instantaneous flux is set by the number and selection of scene types. For the ERBE12 ADMs the instantaneous standard deviation is about 12% for shortwave and about 6% for longwave (Wielicki et al 1995).

**Table 4.5-1: Error in TOA Flux due to Error in ADMs**

Parameter		Current (ERBE12 ADM)		CERES Goal (CERES 200 ADM)	
		SW	LW	SW	LW
global bias	$\sum_{\text{All data}} [E[R_i(\Omega)] - \hat{R}_i(\Omega)]$	1.0%	0.5%	0.2%	0.1%
max bias wrt $\Omega$	$\sum_{\text{All scenes}} [E[R_i(\Omega)] - \hat{R}_i(\Omega)]$	5%	3%	1.0%	0.5%
instantaneous standard deviation for most variable scene	$\sqrt{\text{Var}[R_i(\Omega)]}$	12%	6%	4%	2%

One of the accuracy goals for CERES is to eliminate the global bias. This bias for ERBE came mainly from the flux growth with viewing zenith. The new Radiance Pairs Method (RPM) (see ATBD section 4.5.2.5) of estimating the ADM mean models should reduce the maximum bias with respect to  $\Omega$  to near 1% and cause the global bias to be below 0.2%. The only way to reduce the instantaneous variance is to expand the number of scene types so that each scene has less variance. This will be accomplished by defining 200 scene types for CERES inversion instead of the 12 ERBE scene types.

#### 4.5.5.2 Role of EOSDIS

The operational EOSDIS SSF product will be the data source for the construction of the CERES200 ADMs. All validation tests and construction of ADMs will be done off-line.

#### 4.5.5.3 Plans for archival of validation data

### 4.5.6 SUMMARY

The CERES radiances are inverted to TOA fluxes with mean ADMs. The variance within an ADM scene class goes directly into the instantaneous flux variance which sets the uncertainty in the flux estimate. This variance is reduced by construction of a new set of 200 ADMs instead of the ERBE 12 scenes. The ADMs are validated to establish the erroneous flux growth from nadir views to near limb views. This flux growth is an ADM bias which goes directly into a flux bias.

### 4.5.7 REFERENCES

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# **CERES VALIDATION**

## **CERES INVERSION**

### **TO INSTANTANEOUS TOA FLUXES**

#### **DATA PRODUCTS/PARAMETERS**

**CERES Product: SSF. Parameters: TOA flux, CERES200 ADMs.**

#### **MISSIONS**

**TRMM, EOS AM-1, EOS PM-1**

#### **APPROACH**

**Test ADMs with SAB Method (monthly means, no ADMs)**

**Along-track Test (flux growth with viewing zenith)**

**MISR Comparison (compare to independent data)**

**TOA flux bias and variance determined from ADM bias and variance.**

#### **PRE-LAUNCH**

**Validate ERBE12 ADMs for initial CERES inversion.**

#### **POST-LAUNCH**

**Validate CERES200 ADMs.**

**Intercompare ERBE-like flux and CERES flux.**

#### **EOSDIS**

**EOSDIS SSF product is data source. All validation tests off-line.**